Evaluating conditional sampling strategies for trace-gas flux measurements in urban environments

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To test these conditional sampling techniques in urban turbulence, they were simulated with 80 hourly runs from four existing urban CO2-data-sets (Baltimore, Tokyo, Basel and Berlin). Here CO2-exchange is used as a surrogate for any trace-gas. It was directly measured using high-frequency analyzers at all sites. The data-sets also include temperature, H2O and wind fluctuations at 8 to 20 Hz.

Relaxed Eddy Accumulation (REA)

An updraft and a downdraft reservoir are conditionally filled with air based on the instantaneous value of vertical wind $w$. The reservoirs are later probed by slow gas analyzers and the measured trace-gas concentration difference between the two reservoirs $(c^+ - c^-)$ is related to the flux $wD$, using the coefficient $\beta$ and $\alpha$ [1]:

$$wD = \sigma_w (c^+ - c^-)$$

$\beta$-coefficient: $\beta$ has received much attention in literature [2-4]. For the surface layer, values around 0.56 are reported. The strongly non-Gaussian turbulence driving the exchange above rough surfaces and the non-uniformity of sources in urban areas call for a re-evaluation of its value in urban environments. However, the current urban datasets in general do not suggest a strong departure. Regression slopes at all sites range between 0.50 and 0.60. The dense build-up sites (Baltimore, Berlin) are even closer to the Gaussian prediction [5], but show larger scatter.

To a great extent the conditional sampling techniques in urban turbulence, they were simulated with 80 hourly runs from four existing urban CO2-data-sets (Baltimore, Tokyo, Basel and Berlin). Here CO2-exchange is used as a surrogate for any trace-gas. It was directly measured using high-frequency analyzers at all sites. The data-sets also include temperature, H2O and wind fluctuations at 8 to 20 Hz.

Errors related to deadband width: The current simulation suggests that deadbands width of $\pm \delta$ do not reduce the reliability of the parameterized flux. Higher $\delta$ even lowers the overall RFS in some cases by removing the disorganized around the zero-crossing below. However, above $\delta=1$ statistical significance becomes increasingly lower.

Valves performance: From a practical point of view, it is best to reduce valve switching rates but also to increase the average sampling period. Obviously, a higher $\delta$ lowers the valve switching rate but it also lowers the average sampling period. In any instrumental realization there will always be a trade-off between a high concentration difference, a good statistical significance and a low valve switching rate.

Disjunct Eddy Covariance (DEC)

Instead of a continuous measurement of $w$ and trace-gas concentration $c$, a drastically reduced subset is used to calculate the trace-gas flux. In fixed sampling intervals, air is sucked very fast into reservoirs ($<0.1$ sec) and analyzed during a longer sampling interval. The flux is reconstructed with the small number of measured $c$ and simultaneously measured $w$ [6]. DEC is a direct method. Above urban surfaces, fluxes are typically associated with large coherent structures occupying only small time fractions. Therefore, also DEC has to be carefully simulated with urban CO2-data before measurement systems will be deployed in cities.

Statistical error of the DEC: With increasing sampling interval, the statistical significance of the DEC is lowered. The RFS was calculated for each run and a variety of equally spaced sampling intervals by simulating a large number of realizations using different offsets relative to the first measurement.

Correlation coefficient: It is no surprise that not only narrow sampling intervals (resulting in more sampling points), but also a high correlation coefficient $r_{xy}$ raises the quality of the DEC flux estimation.

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References


Selected urban flux monitoring towers

<table>
<thead>
<tr>
<th>View from tower</th>
<th>Site</th>
<th>Type of tower</th>
<th>Height</th>
<th>Instrumentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cork Hill</td>
<td>Baltimore</td>
<td>40 m</td>
<td>Sonic (Young USA)</td>
<td>Closed Path (LY000)</td>
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<tr>
<td></td>
<td>Vegated suburban</td>
<td>40 m</td>
<td>Sonic (Young USA)</td>
<td>Closed Path (LY000)</td>
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<td>Tokyo</td>
<td>29 m</td>
<td>Open Path (LY0750)</td>
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<tr>
<td>Kugahara</td>
<td>29 m</td>
<td>Open Path (LY0750)</td>
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<tr>
<td>Dense urban</td>
<td>29 m</td>
<td>Open Path (LY0750)</td>
<td></td>
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<tr>
<td>Klingenbergstrasse</td>
<td>38 m</td>
<td>Open Path (LY0750)</td>
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<tr>
<td>Dense urban</td>
<td>38 m</td>
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<tr>
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<td>Stiegler Kreisel</td>
<td>119 m</td>
<td>Sonic (metek USA)</td>
<td>Open Path (LY0750)</td>
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<tr>
<td>Regional / urban</td>
<td>Berlin</td>
<td>119 m</td>
<td>Sonic (metek USA)</td>
<td>Open Path (LY0750)</td>
</tr>
</tbody>
</table>

The REA-Deadband

Practically, a deadband of width $\pm \delta$ is excluded from analysis in order to reduce valve switching around the zero-crossing of $w$ and $c$. To increase the concentration differences in the two reservoirs.

$\beta$-coefficient as a function of deadband width: Dissimilarities between the fluxes of CO2, sensible heat and H2O are reflected by different $\beta$-coefficients. Runs with a wide deadband show significant departures between the different scalars and sites. The theoretical $\beta$-coefficient as a function of $\delta$ for a Gaussian distribution is drawn in black.

Correlation coefficient: It is no surprise that not only narrow sampling intervals (resulting in more sampling points), but also a high correlation coefficient $r_{xy}$ raises the quality of the DEC flux estimation.

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